The QVD Sensor as a Focal Plane Instrument for Con-X

Presented by
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and
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QVD Detectors

X-ray calorimeters for high energy resolution, high event rate, in focal-plane arrays

Q=Heat, V=Voltage, D=Digital

QVD sensors

- **Invented at NRL**
- **US Patent** *No. 6,710,343* **2003**

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Nuclear Instruments and Methods in Physics Research A 444 (2000) 232–236

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

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X-ray/UV single photon detectors with isotropic Seebeck sensors

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Abstract

A novel hot-electron microbolometer concept suitable for hyperspectral imaging at high photon counting rates is

Why QVD sensors?

2 niches

- high resolution calorimetry (with high event rates)

- very high event rates for classical X-ray timing (QPOs)

- **Fastest detectors among microbolometers**
  - **Operates orders of magnitude faster than its competitors**
- **No sacrifice in energy resolution (theoretically)**
  - **Theoretical limits are comparable to the best in the field**
- **Arraying schemes**
  - **"Book" architecture, to be described**
  - **Other schemes also shown**

What are the difficulties?

Severe resource limitations

- QVD funding < 100k/yr, covered experiment, theory, proposal writing

- Needs NASA funding because of limited DoD relevance
- Funding shortage resulted in slow-down after 2004, but we are still hoping to pursue it. Results here are 2003-4.

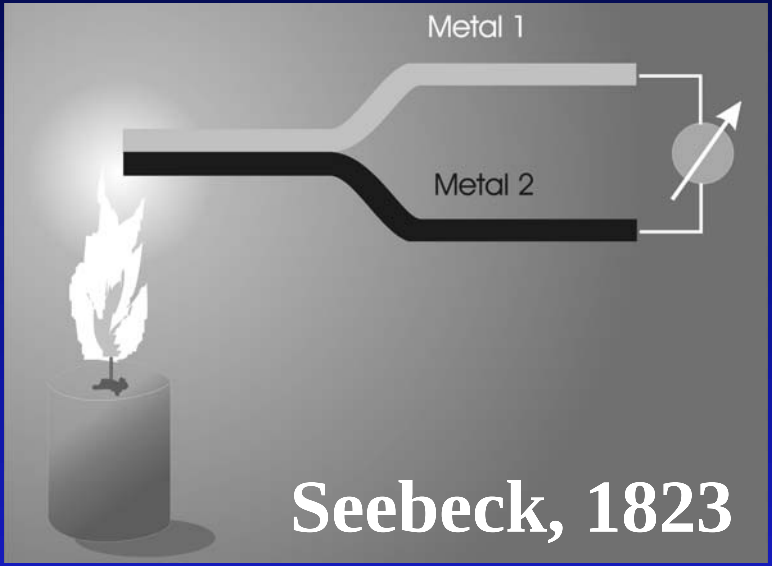
We have subsequently pursued some related applications (refrigeration), accumulated equipment, done materials studies – and have been drawn away to things that paid better and got more encouragement.

Have tried test samples for single pixel devices

- Better designs conceptualized, moving towards fabrication
- Speed of response demonstrated

TRL is ~ 3-4; candidate for APRA

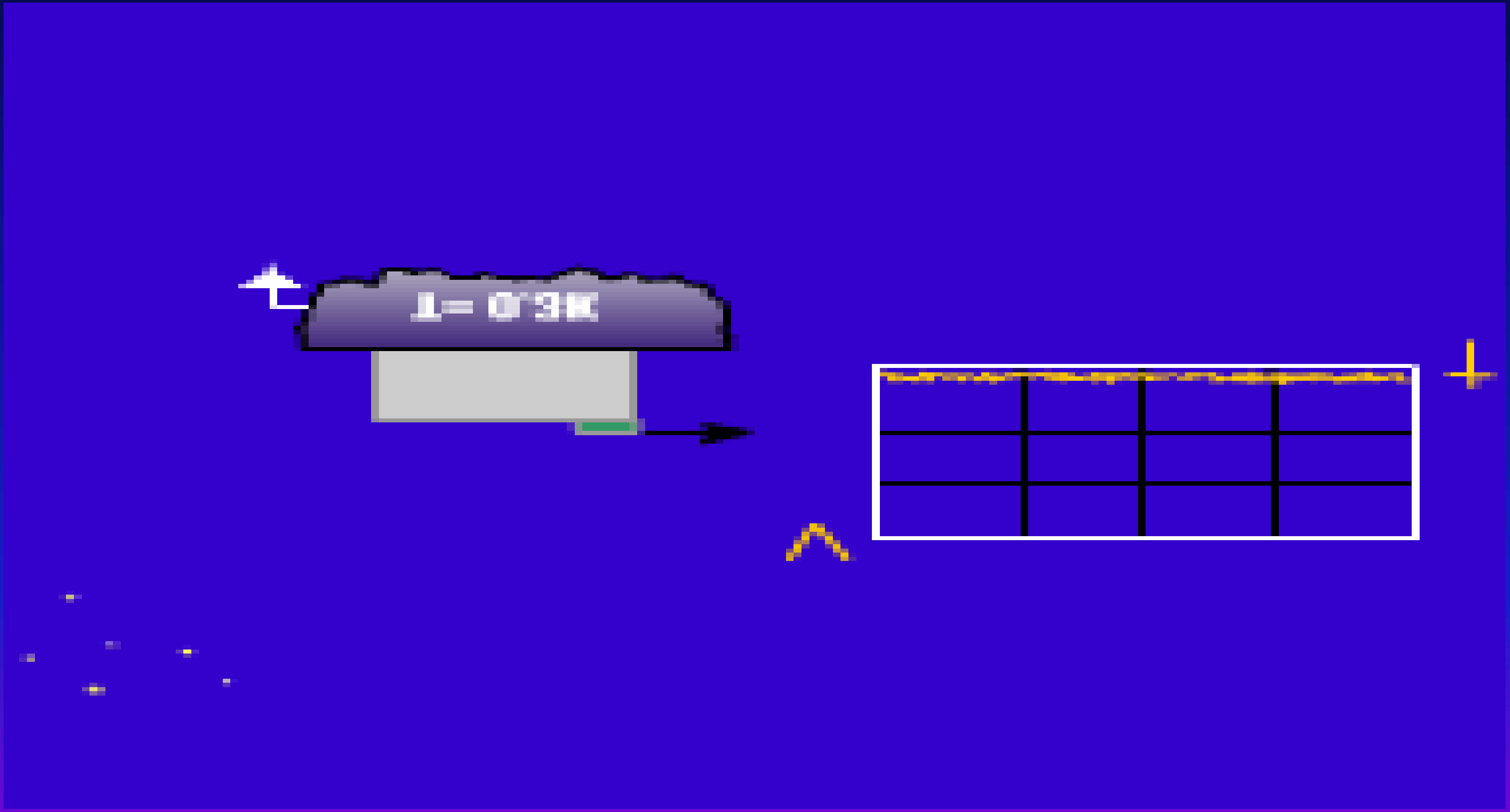
Background physics



- **Heating the junction of two different metals creates a current in the circuit**

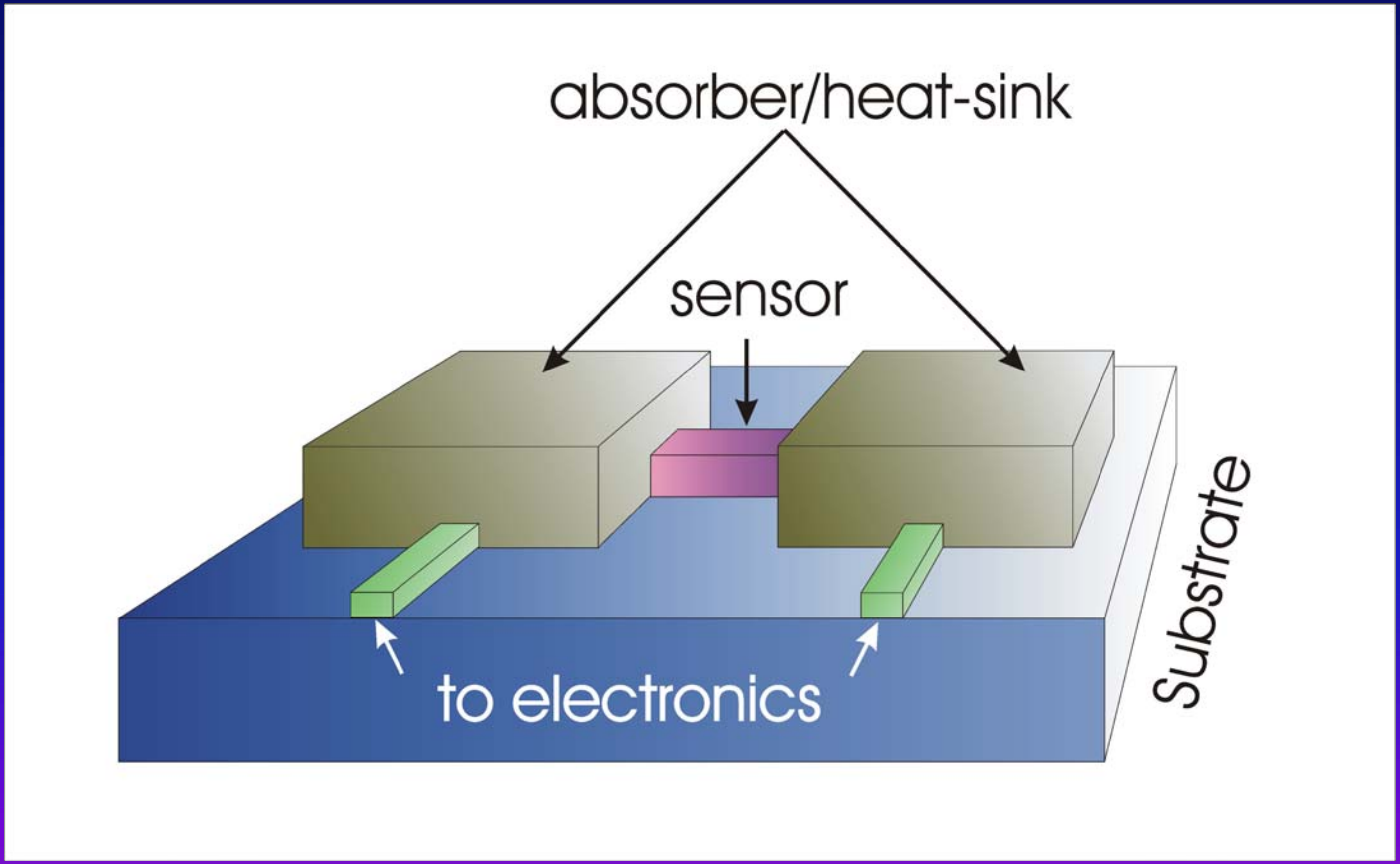
QVD: how it works

(simplest primitive concept)



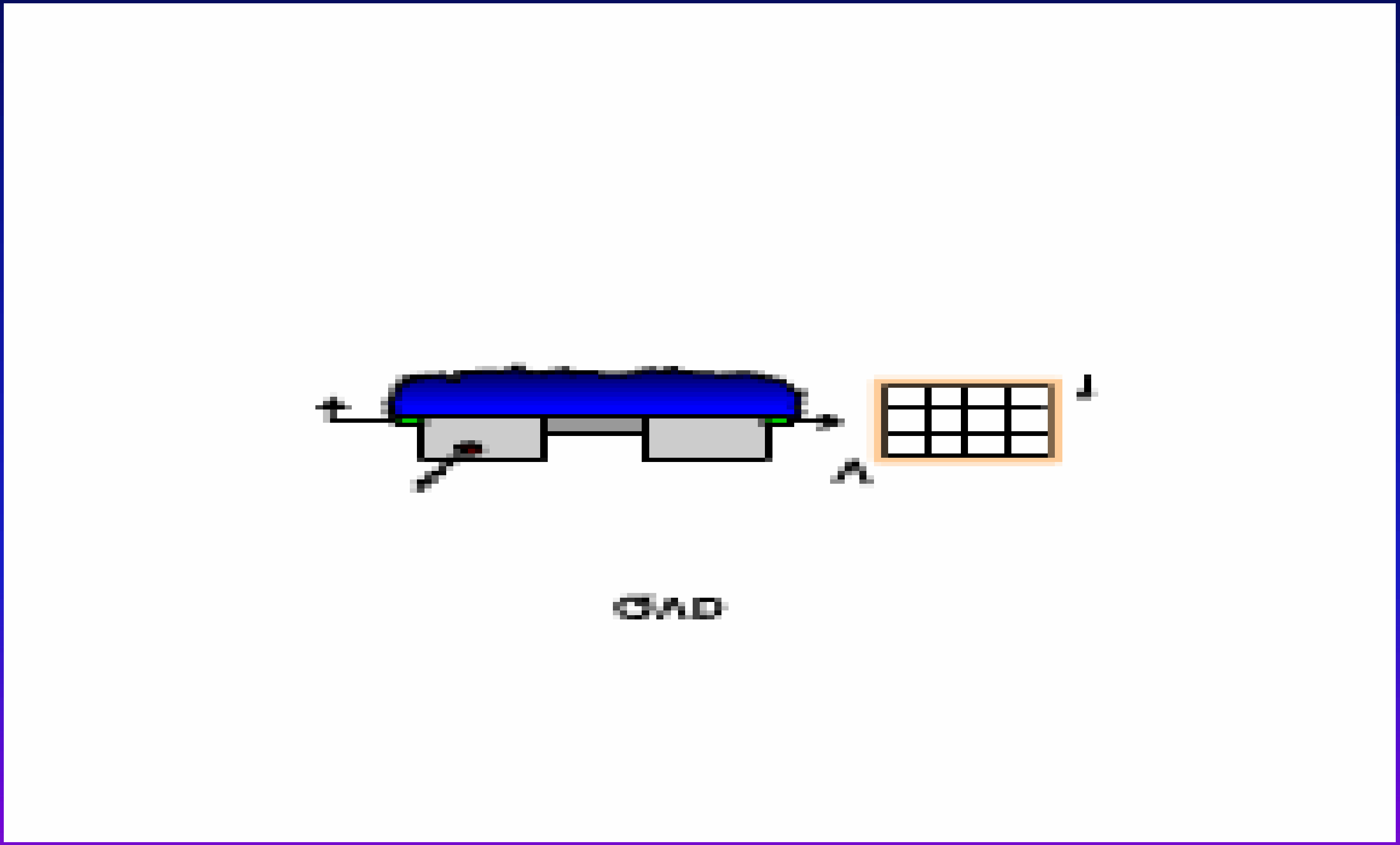
QVD: second scheme

thin-film device



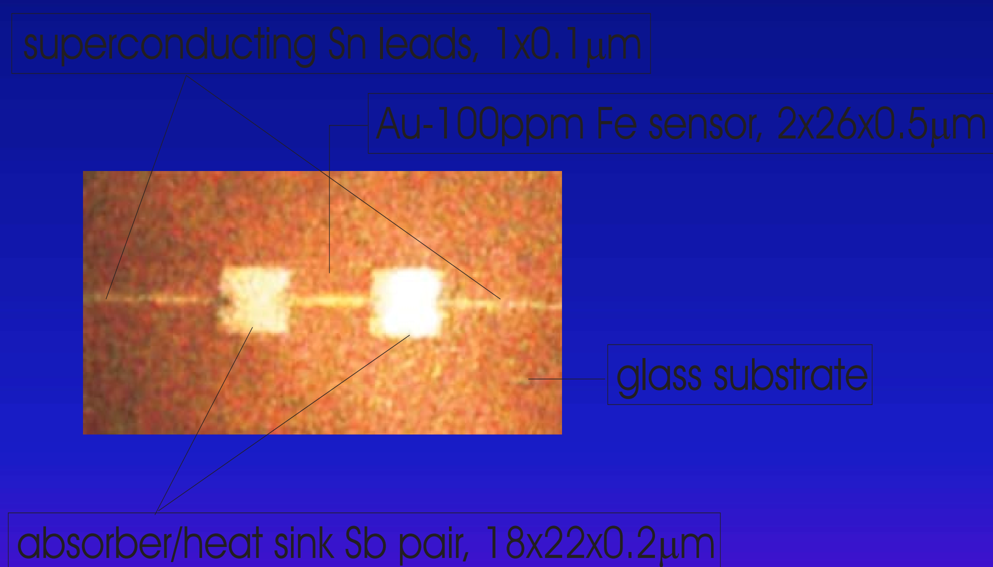
Binary concept: 1 readout for 2 pixels

(Photon onto right pixel would produce negative pulse)

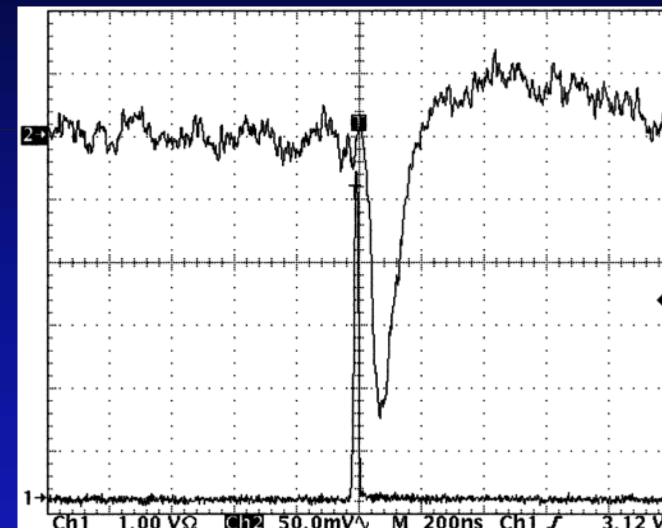


Validating QVD concept

c. yr 2000:

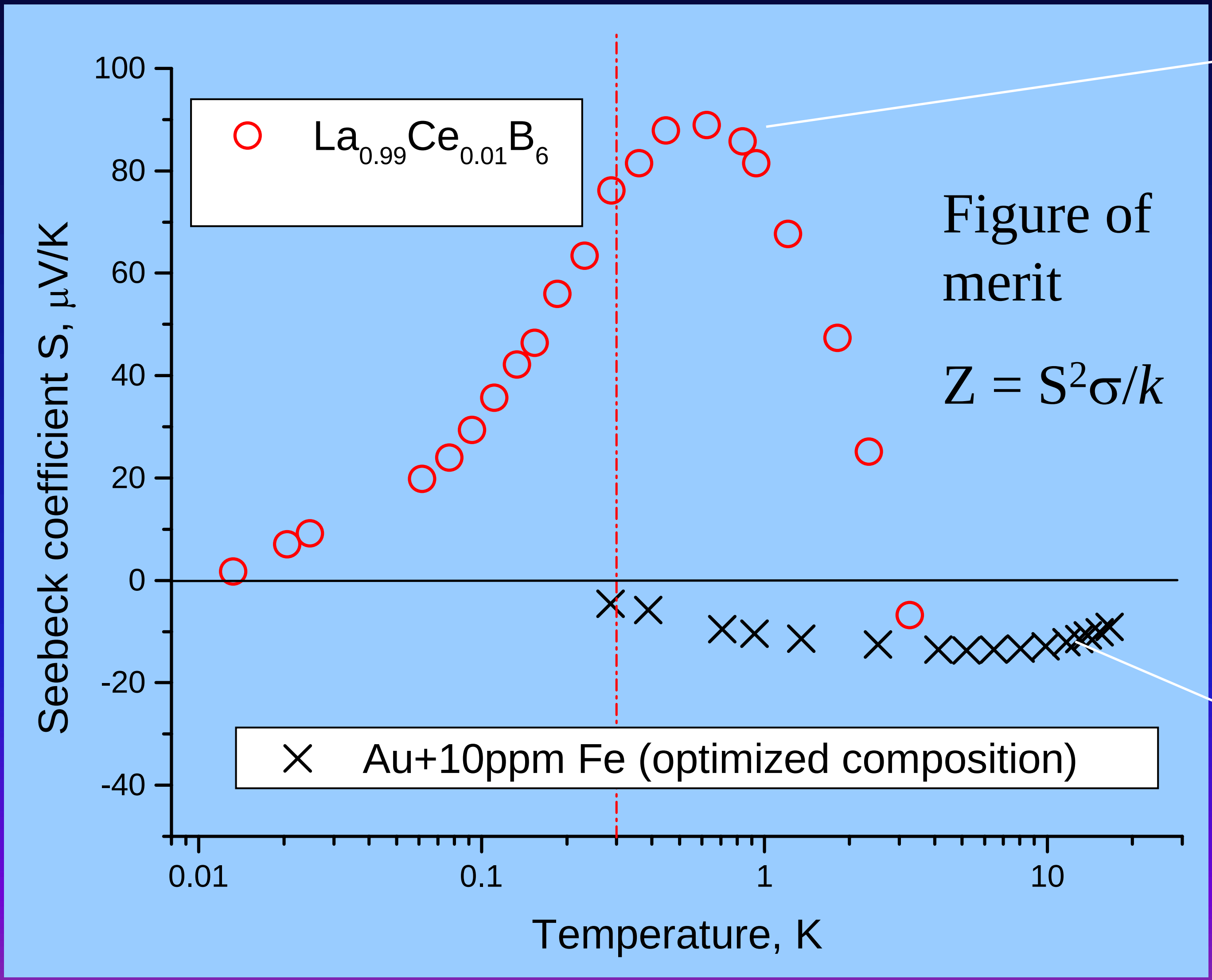


Au-Fe sensor prototype device



Detector output in response to the laser-pulse energy input to one pixel

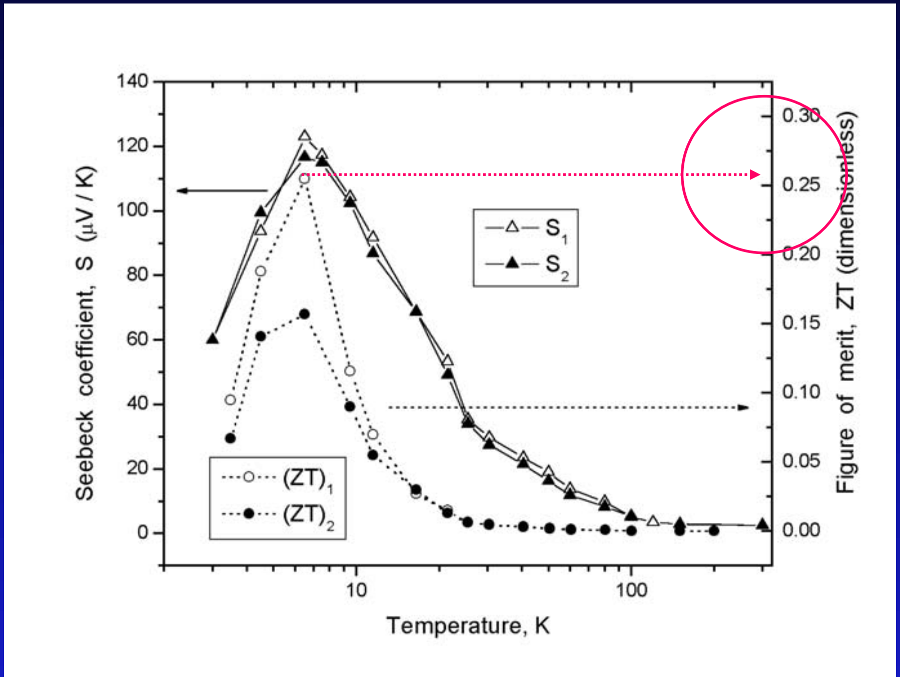
QVD: sensor materials

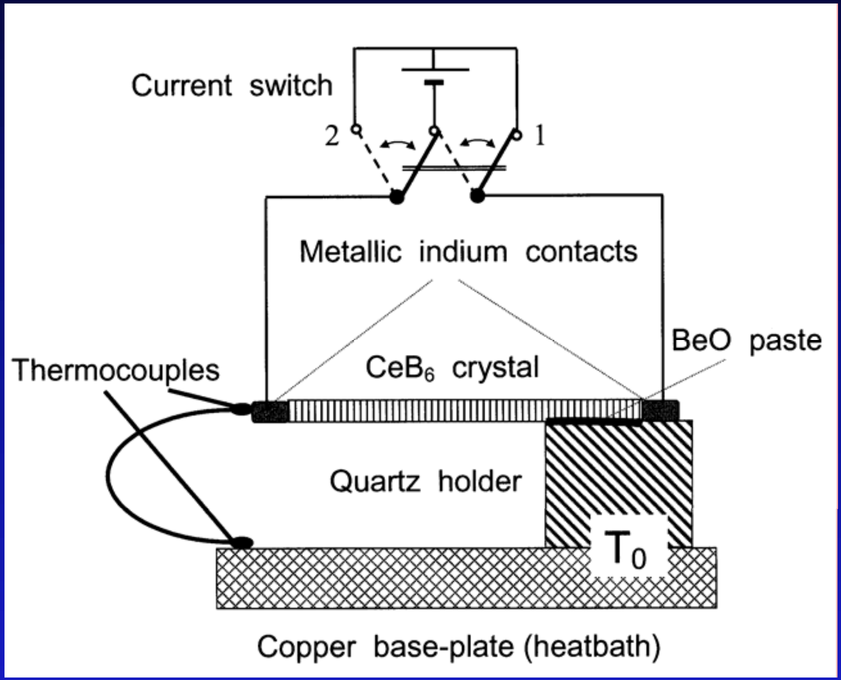


New material: LaB_6 with 1% Ce substitution for La provides very high figure of merit (ZT ~0.2).

Previous best material Au-Fe has ZT ~0.005

Proof for ZT: Refrigeration





- High values of ZT for hexaborides were demonstrated in our work via Peltier cooling (reciprocal to detector action) with CeB_6 crystals
  - Special purpose refrigerator
  - [Appl. Phys. Lett., 83 (11) Sept., 2003]

QVD: theoretical energy resolution

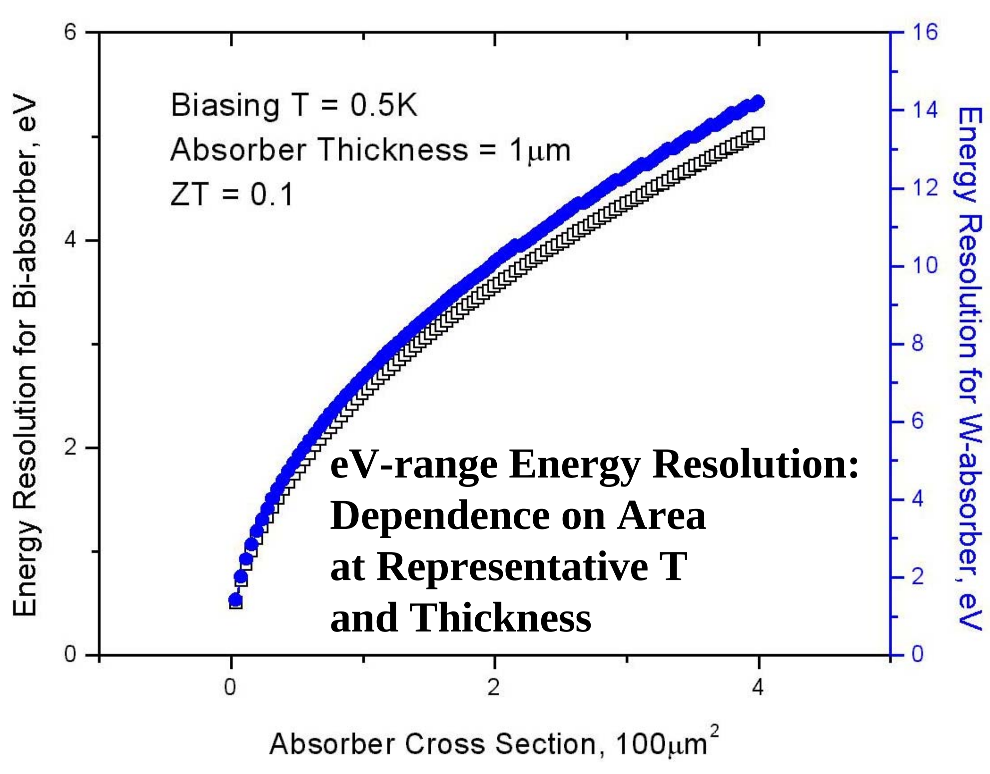
$$\Delta E_{FWHM} = 2.35\{2k_B\, T^2\, C_{abs}[1+(ZT)^{-1}]\}^{1/2}$$

For $ZT \sim 0.2$

$C_{abs} \sim 1fJ/K$

$T \sim 300mK$

$\Delta E_{FWHM} \sim 1.84$ eV



[A. Gulian *et al.*, NIMA, <u>444,</u> 232 (2000)]

How fast can QVD be?

For microbolometers, in general,

the bottleneck is heat-escape (Kapitza) time:

$\tau_K \sim 1/T^3$.

Then counting rate $\sim 1/\tau_K \sim T_{op}^3$.

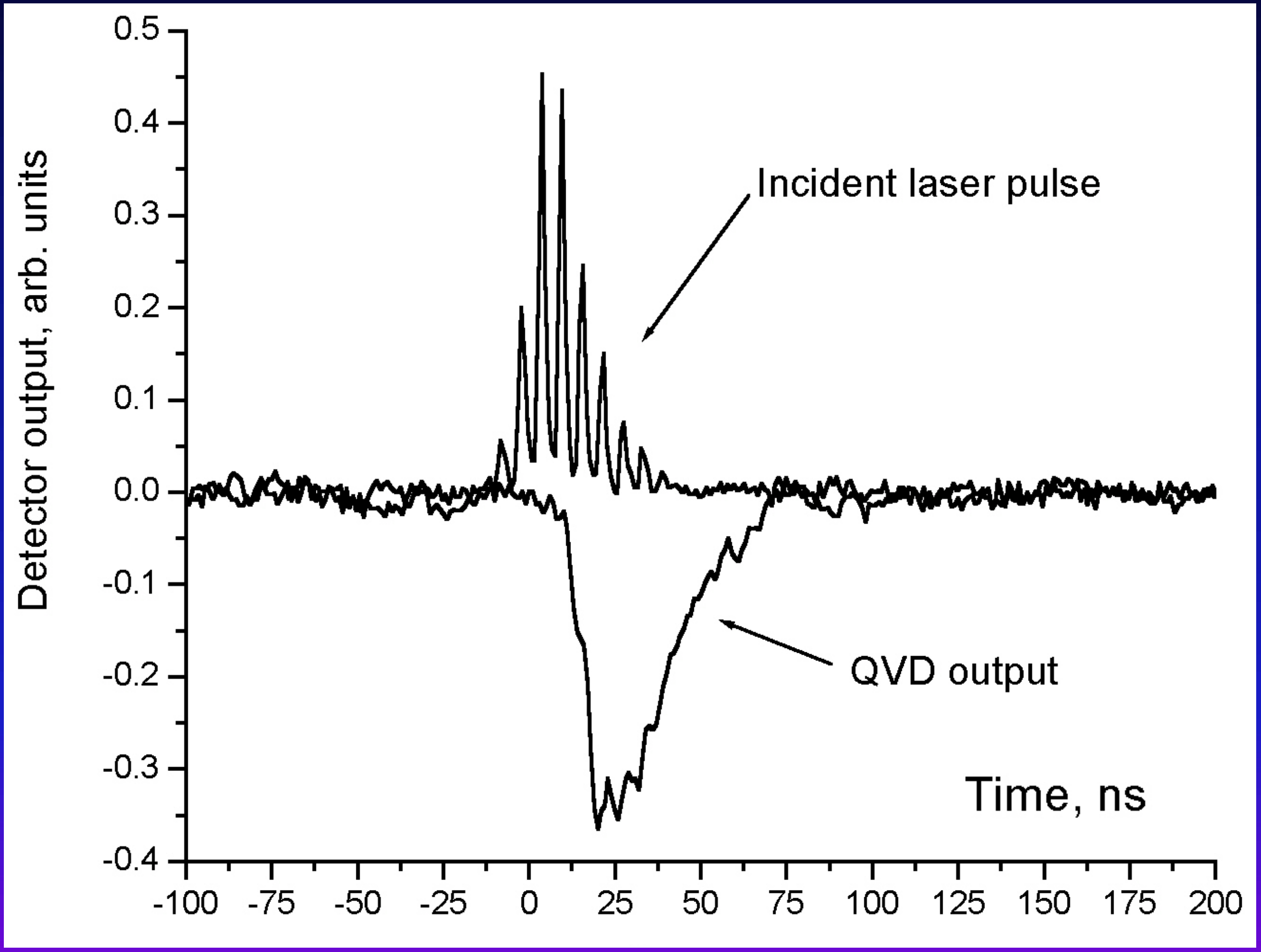
Comparing QVD with TES:

$T_{op}^{QVD}/T_{op}^{TES} \sim 500\mathrm{mK}/50\mathrm{mK} = 10$

Thus counting rates of QVD can be 1000 times faster…

This presumes that inherent speed of thermoelectric sensor is not a bottleneck. It is not! – Next Slide

QVD: high speed demonstrated



Peaks in input are separated by 7 ns intervals

Response FWHM ~20 ns

A. Gulian *et al.*, J. Modern Optics, <u>51</u>(9), pp.1467-1490 (2004)]

QVD: digital readout

- Dedicated pixel readout
  - QVD output is amplified by a dedicated SQUID-array amplifier
  - And digitized by existing cold (superconducting) A/D converter in the cryostat

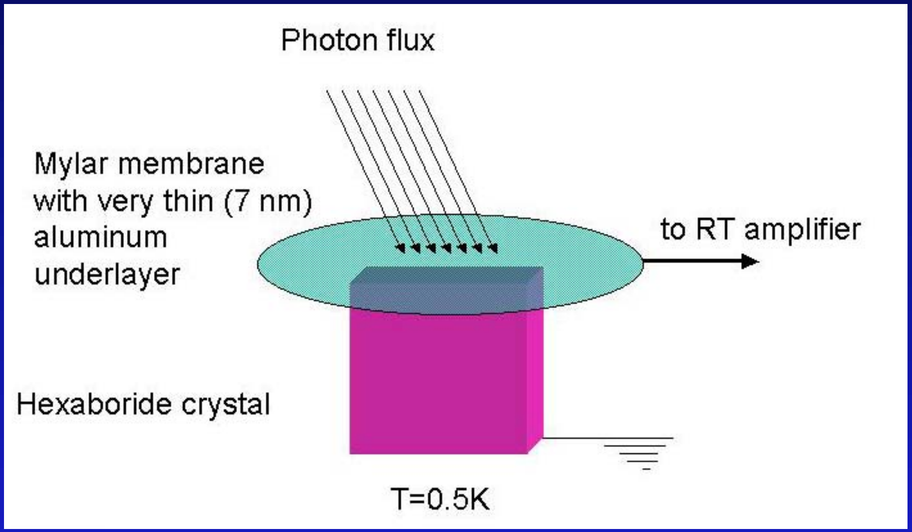
Thermal balance estimates (T_{op} ~ 300-500mK >>50mK; this is important!) show that it will be possible to arrange for small and moderately large arrays (>1000 pixels tolerable).

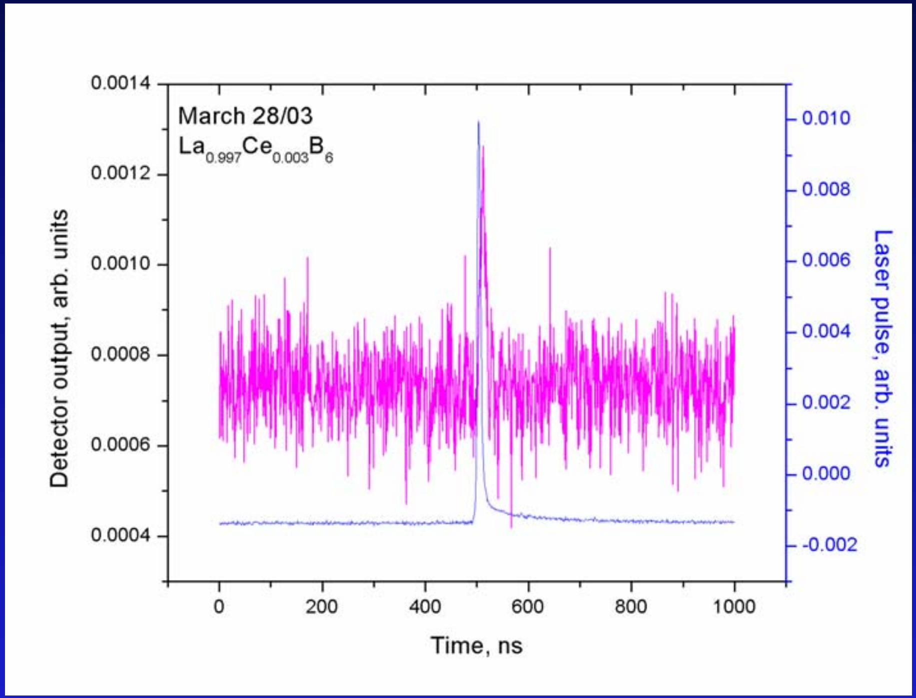
- Alternative: multiplexing

This approach takes advantage of

  - Already demonstrated multiplexing schemes for various single-photon detector techniques
  - Other DoD developments
  - Interest in digital electronics community (ONR, HYPRES, SUNY).

First detector with La(Ce)B_6 sensor





Sensor: $La_{0.997}Ce_{0.003}B_6$ crystal from Goettingen, Germany

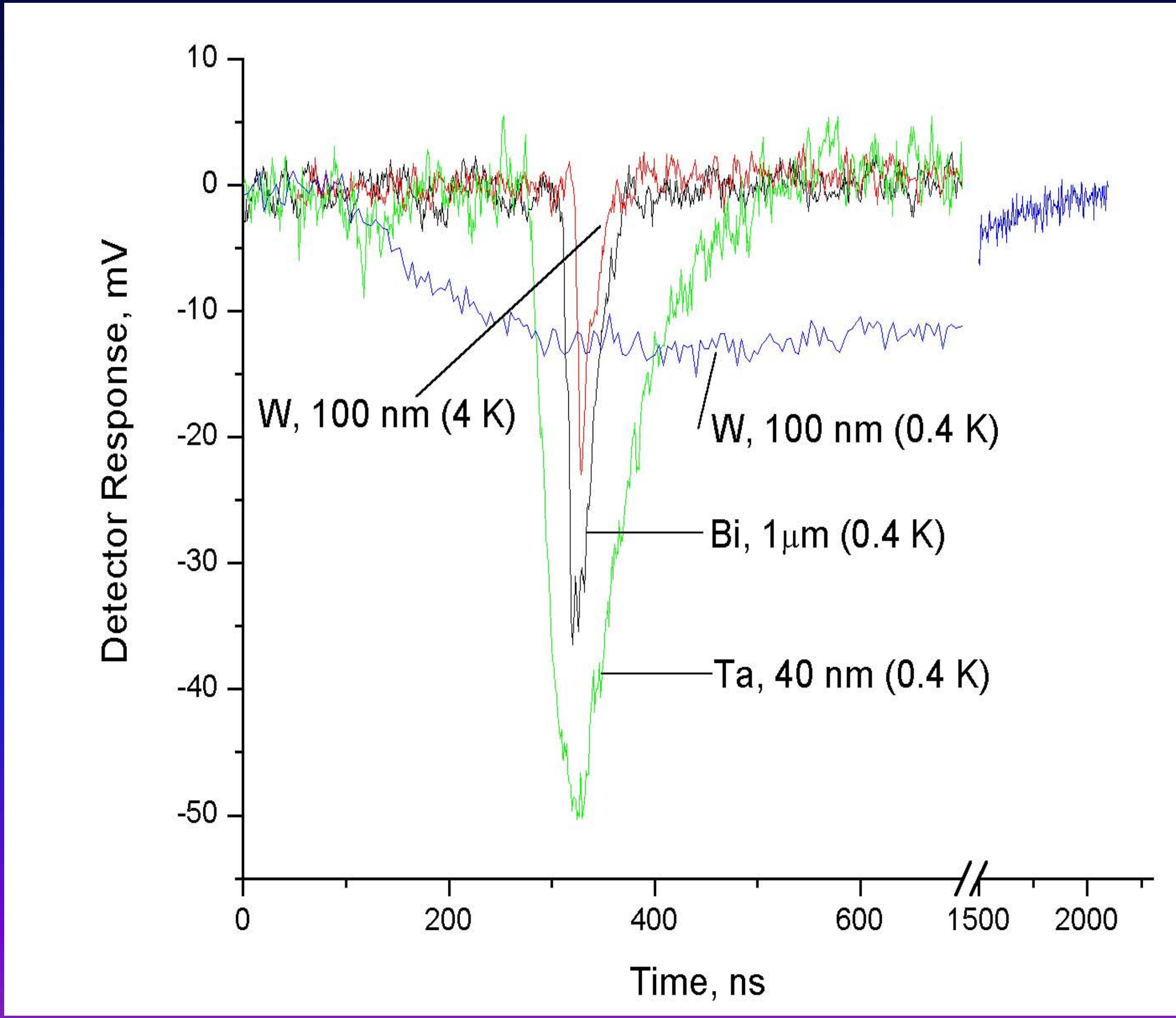
Choosing absorber materials

Tested

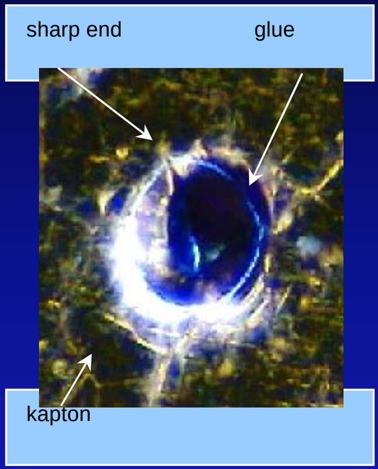
W

Ta

Bi – best choice

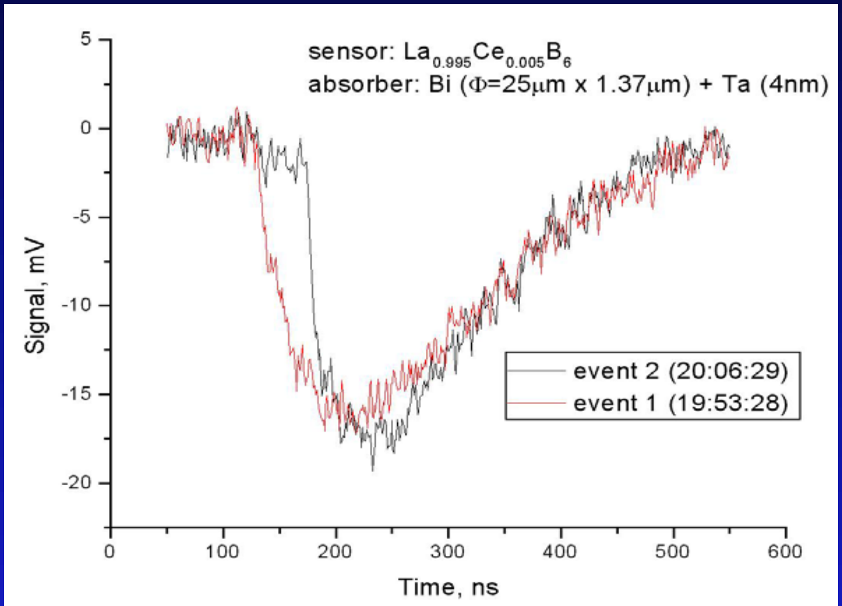


Resolving single X-rays by QVD



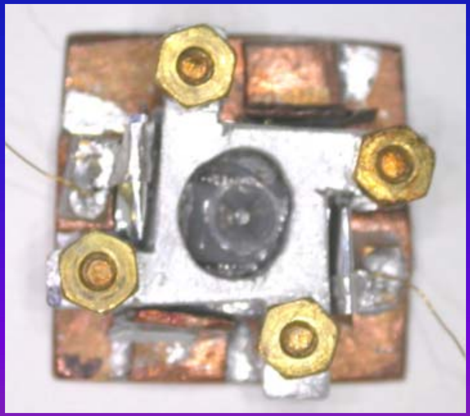
Sensor module

Absorbers



Two photons registered!

Detector assembled from these parts



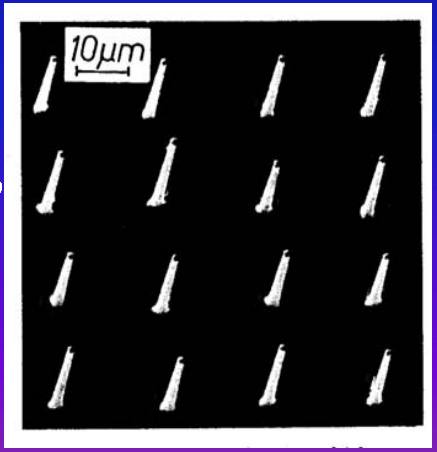
Status

Sensor crystals identified and imported free of charge from

- ***Germany (Prof. Winzer, U. Goettingen)***
- ***Japan (Prof. Kunii, Tohoku U.)***
- ***Russia (Prof. Gurin, Ioffe Inst., St-Petersburg)***

High-quality crystals available from a US supplier
(Prof. Z. Fisk, Florida U.) in case of ~20K/year support.

Very unique opportunity in negotiated with Prof. Givargizov (Crystallography Inst., Moscow). This requires one-time 100K$ + 10K$/per 1000x1000 sensor array:



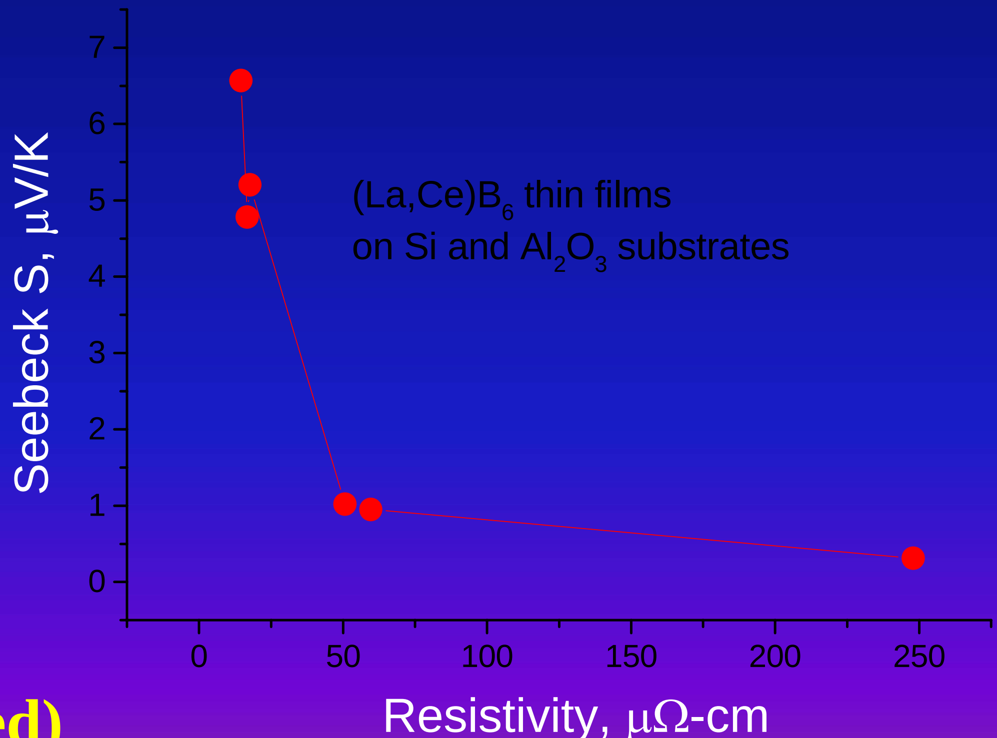
Array-ready design

Status *(continued)*

Thin films for sensors is another possibility

- In-house efforts to produce films
- Quality of films already enables pursuing 10eV-range prototype detectors.

Lack of funding delayed arrival of devices tackling energy resolution (thin film/crystal – both pursued)



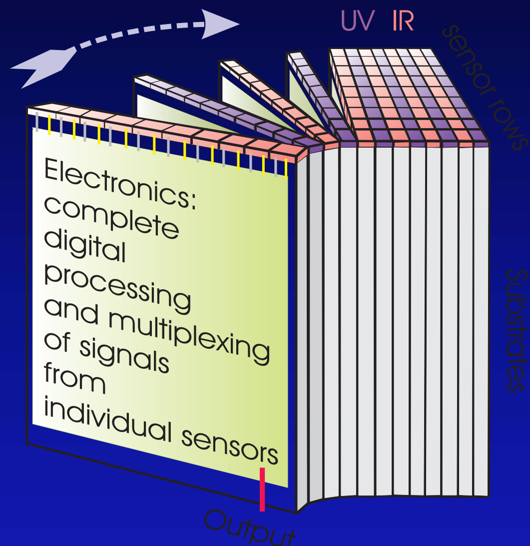
Status *(concluded)*

Some progress is possible at existing small support, but it will not be fast!

Need sponsor or collaborative partners, or both. Need money either way.

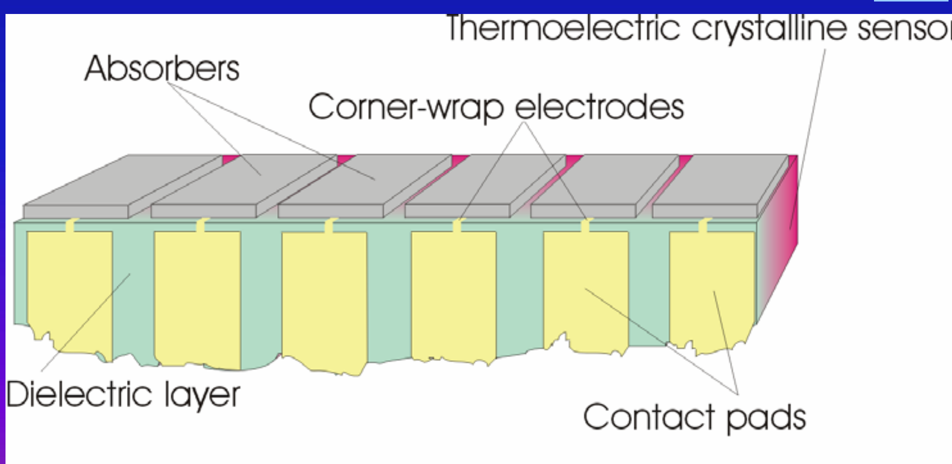
QVD: arrays, multiple choices

1



Detail of one "page"

2



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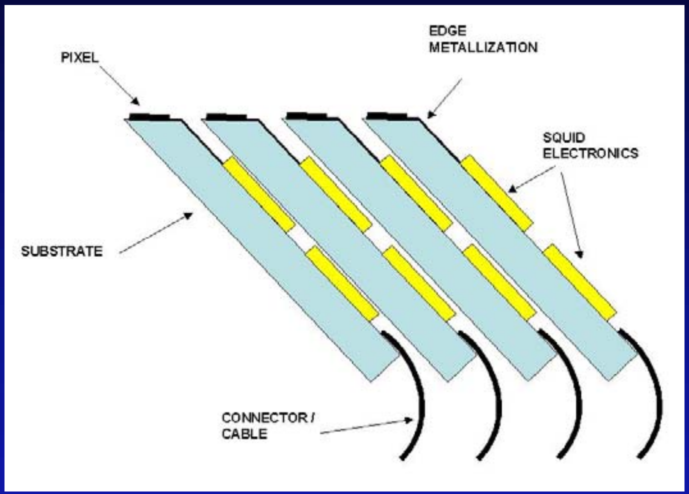

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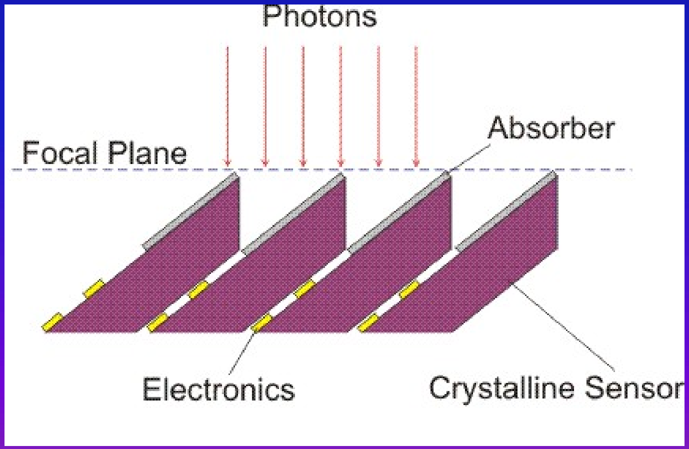

Summary

- **For a modest investment of NASA money, QVD offers the potential of a Con-X detector with:**
  - **< 2 eV resolution (*i.e.*, R ~3000)**
  - **> 1,000,000 counts/s/pixel with NO pileup!**
  - **Arrays of up to 1000 pixels with direct readout, and 1000x1000 with multiplexed readout (at lower count rates)**
  - **Finer pixel resolution than TES**
  - **Order of magnitude higher operating temperature than TES**